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Characteristics of Composition B particles from blow-in-place detonations

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Abstract

We sampled residues from high-order and low-order blow-in-place detonations of mortars and projectiles filled with Composition B (Comp B), a TNT and RDX mixture. Our goals were to (1) characterize the types of explosive particles, (2) estimate the explosive 'footprint' for different munitions, and (3) estimate the mass of Comp B remaining after each detonation. The aerial deposition of Comp B particles helps estimate how large of an area is contaminated by a low-order detonation and how best to sample residue resulting from different rounds.

We found that the high-order detonations deposited microgram to milligram quantities whereas the low-order detonations deposited gram quantities of Comp B. For the high-order detonations the concentration of Comp B in the residue decreased as a function of distance from the blast. The low-order tests scattered centimeter-sized chunks and millimeter-sized or smaller particles of Comp B. The chunks were randomly scattered whereas the number of millimeter-sized particles decreased with distance from the detonation. For both high- and low-order detonations we found that the smaller munitions deposited less Comp B than the larger munitions and deposited it closer to the detonation point.
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1. Introduction

Estimating the load of explosives on Department of Defense training ranges requires knowing how much high explosive (HE) is deposited by the detonation of a munition and how this amount varies if the detonation is low- or high-order. The subjective term "order" is used as a proxy for explosive yield, how much of the high explosive was expended in the detonation. An observer would classify as high order (HO) any explosion indistinguishable from 100% yield and as low order (LO) an explosion clearly sounding or looking different from 100% yield.

Because all of the residue cannot be collected, different strategies have been used to collect a portion of the residue. Snow (Jenkins et al., 2000; Lewis et al., 2002), tarp (Pennington et al., 2003) and tray (Taylor et al., 2004a,b) samples have been used to estimate the mass of explosive residues. Each of these methods has advantages and disadvantages.

Snow samples are fairly easy to collect. The new snow is a clean substrate that minimizes cross-contamination with range soils that may contain explosives. Furthermore the location of the samples can be determined after the detonation. A disadvantage is that at least three snow samples, each consisting of 100-increments, are required to adequately represent the average HE concentration of the surface snow (Walsh et al., 2005a). Also HE particles or chunks, especially if they are hot, may travel into the snow and not be collected by these surface samples.

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14. ABSTRACT

We sampled residues from high-order and low-order blow-in-place detonations of mortars and projectiles filled with Composition B (Comp B), a TNT and RDX mixture. Our goals were to (1) characterize the types of explosive particles, (2) estimate the explosive ?footprint?for different munitions, and (3) estimate the mass of Comp B remaining after each detonation. The aerial deposition of Comp B particles helps estimate how large of an area is contaminated by a low-order detonation and how best to sample residue resulting from different rounds. We found that the high-order detonations deposited microgram to milligram quantities whereas the low-order detonations deposited gram quantities of Comp B. For the high-order detonations the concentration of Comp B in the residue decreased as a function of distance from the blast. The low-order tests scattered centimeter-sized chunks and millimeter-sized or smaller particles of Comp B. The chunks were randomly scattered whereas the number of millimeter-sized particles decreased with distance from the detonation. For both high- and low-order detonations we found that the smaller munitions deposited less Comp B than the larger munitions and deposited it closer to the detonation point.

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A large tarp can collect most of the chunk and mm-sized HE particles allowing a mass balance to be calculated. Its disadvantage is that the tarp is difficult and time consuming to clean; small particles can remain on the tarp or be caught in the brushes used to sweep the tarp. Also as tarps are expensive they are used multiple times. Cross-contamination may not introduce large errors for LO detonations but certainly will if HO detonations are sampled from a previously used tarp.

Trays are easy to use. In the absence of a strong wind they retain all the materials landing on them and the area of each tray is well defined. As with snow samples the area of each tray is small compared to the area of residue deposition so many trays have to be used to adequately sample the HE residue.

In this study we estimated the explosive mass remaining after high- and low-order detonations using both tray and tarp samples and we counted the number of explosive particles on the trays after LO detonations. Our goals were to (1) characterize the types of explosive particles, (2) estimate the explosive 'footprint' for different types of rounds, and (3) estimate the mass of Comp B remaining after each detonation. We describe our results for Comp B -filled 60-mm, 81-mm, 105-mm and 120-mm rounds. Comp B is a 39–60 mixture of TNT (2,4,6-trinitrotoluene) and RDX (hexahydro-1,3,5-trinitro-1,3,5-triazine) that contains ~1% wax. Also HMX may be present as military grade RDX can contain up to 10% HMX as a manufacturing impurity. Comp B is a widely used explosive which is of environmental concern because RDX is known to have contaminated groundwater beneath impact areas at Massachusetts Military Reservation, MA, (USEPA, 2000) and at Fort Lewis, WA (Jenkins et al., 2001). Models that determine the mass transfer of Comp B from the solid phase to the water (Lynch et al., 2002; Lever et al., 2005) require the masses, sizes, and surface areas of the particles as input parameters.

2. Methods

2.1. Field site

We conducted tests at the Army Research Laboratory facility in Blossom Point, MD, as part of a larger study of LO detonations (Pennington et al., 2003). A wooden stand was used to hold the round vertical to the surface, nose pointing up. The 60, 81 and 120 mm rounds were fitted with an empty fuze, the 105 mm rounds with carrying lugs. The fins were removed. All rounds were detonated using a main charge disruptor, a tool that pierces the munition's shell using a small shape charge containing C4 (Pennington et al., 2003). To avoid having the explosion interact with the ground and entrain the soil, the rounds were detonated in the center of a white, vinyl, flame-resistant tarp, on top of a 184- × 230- × 6-cm-thick steel table with an 86-cm-high wooden base (Fig. 1). The detonations were classified as HO or LO based on air-blast explosive yield measurements (Pennington et al., 2003). We did not take meteorological conditions into account.

Table 1 lists the types of 60-mm, 81-mm, 105-mm and 120-mm detonations sampled. We counted the number of HE particles on trays set out at different distances from the detonation (Fig. 1). The first tray was either 2 or 3 m from the detonation point and the other trays placed at 2-m intervals along a southeast direction. The last tray was often placed farther than 2 m from the second to last tray. A southeast direction was chosen because the main charge disruptor pierced the shell on its north-facing side and the southeast quadrant generally contained residues. Following the detonation, the material on each tray was weighed and examined under a microscope.

2.2. Sample processing and analysis

Since no explosive particles were seen on the trays after the HO tests, we analyzed the residues using high performance liquid chromatography (HPLC) as described below. The HO detonation residues were collected using new trays as the HPLC has a low detection limit and we wanted to avoid any possibility of cross-contamination.

The residues from the LO detonations contained many Comp B particles. To help us sort the material we sieved each sample into <250 μm, 250–2000 μm, and >2000 μm size fractions. We separated the explosive particles larger than 250 μm from the wind-blown soil under a Wild M8 binocular light microscope. These Comp B particles were then photographed using a microscope, and the photographs digitally processes using the National Institute of Health's image software program (NIH Image) to obtain the number of particles and measure the length of each particle's major and minor axis (Taylor et al., 2004a). The axes lengths were used to calculate an average diameter of each particle and the mass ($\rho = 1.65$ g/cm^3). We estimated the mass of Comp B in the <250 μm size fractions by HPLC.

The samples extracted for chemical analysis were weighed, placed in a known volume of acetonitrile and shaken overnight. The extracts were then analyzed following method 8330 (EPA, 1994), the standard method for determining explosive residues in water and soil. One milliliter of the acetonitrile extract was added to 3 ml of distilled water and filtered through a 0.45 μm Millipore cartridge. The HPLC was fitted with a Water NovaPak C8 column, eluted at 1.4 ml/min (28 °C) with a 85:15 water:isopropanol mix and the compounds detected by UV at 254 nm. This set-up separates HMX, TNT, DNT, and their co-contaminants. Commercially available standards (Restek), specifically developed for Method 8330, were used for calibration.

A Zeiss DSM962 Scanning Electron Microscope was used to image and perform qualitative analysis on whole and sectioned particles of Comp B. The explosive particles were coated with carbon and a 10 keV accelerating voltage was used for analysis and imaging.

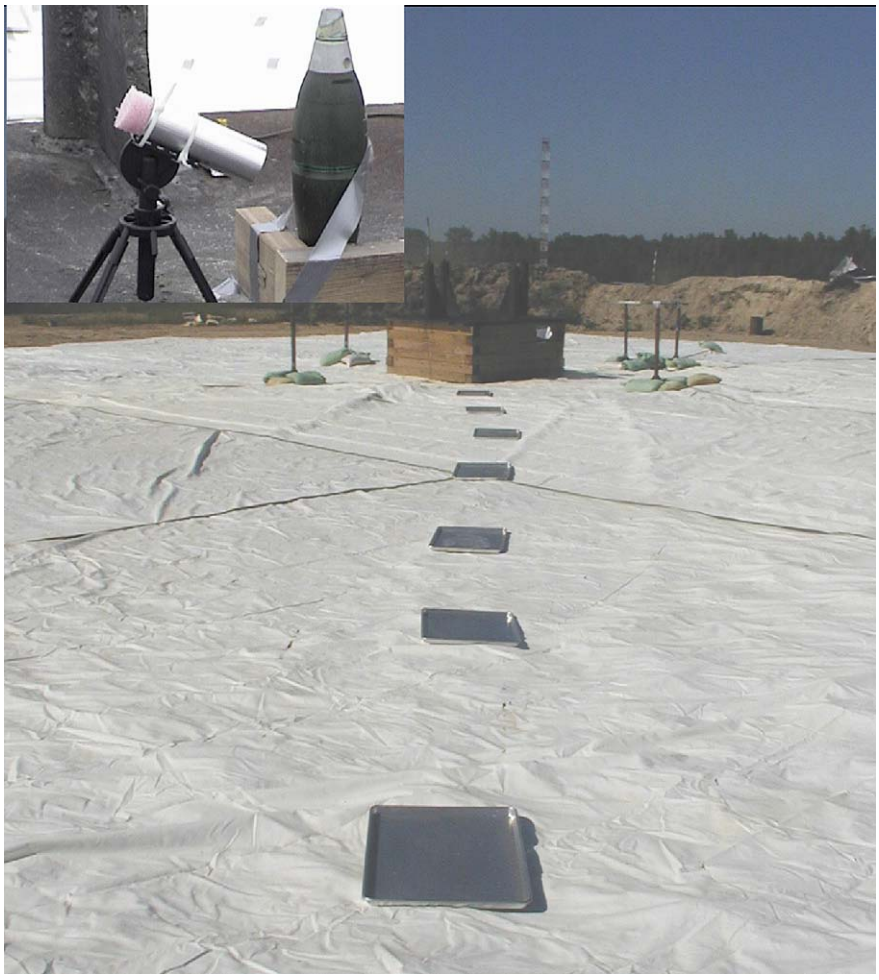

Fig. 1. Experimental set-up at Blossom Point. Eight trays were placed along a southeast line. The inset shows a 81-mm round set-up for detonation.

Table 1
Rounds sampled at Blossom Point, Maryland

Round	Date	Shot #	# tests	Sampling method	HE in round (g)	Estimated HE mass	Units
M720							
HO-60	Aug-03		3	8 trays	190	20, 18, 0.7	mg
LO-60			2	8 trays		11, 136	g
M821							
HO-81	Sep-02		1	8 trays	727	40	mg
LO-81		LO-1 and 2	2	8 trays + pieces		494, 164	g
		LO-1, 2 and 3	3	Tarp + pieces		433, 51, 264	g
M1							
HO-105	Aug-03		1	8 trays	2310	No data	
LO-105		12 and 13	2	8 trays		345, 224	g
M934							
HO-120	Jun-04		1	8 trays	2990	4685	mg
LO-120			4	8 trays		614, 414, 127, 135	g

3. Results and discussion

3.1. Characteristics of Comp B particles

The residue collected from the Comp B-filled rounds ranged from carbon residues for some HO detonations to centimeter-sized pieces of Comp B for low-order detonations. Microscopic observations indicate that the HO residue contains melted metal spheres, fragments of wood and soil. Although it is generally not possible to see the high explosive (HE) particles, the residues contain some HE as evidenced by HPLC analysis. Microscopic observations

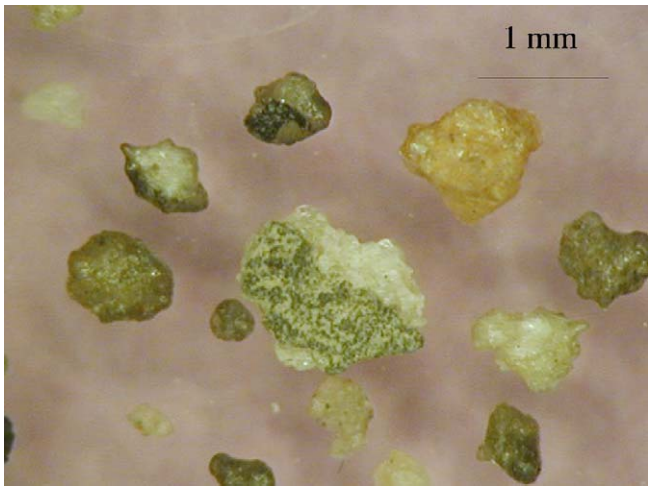

Fig. 2a. Different types of Comp B particles, crystalline to melted, are found in residues of partial detonations.

show that the LO residue contains rounded and lumpy particles of Comp B, aluminum and iron fragments, large pieces of wood and soil. The Comp B varied from white, gray, or pink crystalline particles, to botryoidal yellow and black particles that appeared to have been heated, to yellow and black spheres that had been melted (Fig. 2a). Some of the millimeter-sized particles had been hot or molten when they landed on the trays, as they adhered to the trays and had flat bottoms. We think that the change from yellow to black is due to the presence of soot in the particles. TNT produces carbon soot when detonated because it is oxygen deficient and not all the carbon atoms are paired with oxygen atoms. The LO detonations also scattered centimeter-sized chunks of fragmented crystalline explosive on the tarp.

When examined under a scanning electron microscope, a sectioned Comp B particle contains discrete RDX grains embedded in a much finer grained TNT matrix (Fig. 2b). Because Comp B is a mixture whose constituents have different physical properties, such as melting points, we wondered if the different types of Comp B particles had different compositions resulting from their heating histories. We selected crystalline, partially melted, and totally melted Comp B particles and analyzed the particles separately. The results show a wide range in the RDX/TNT ratio (0.48–2.69) but no systematic change in composition as a function of particle appearance. We think the compositional variability is due to mm-scale inhomogeneities in the Comp B.

3.2. Residue extent or 'footprint'

For sampling purposes it is useful to know how far explosive residues are scattered after a detonation and the amount of HE per square meter. Our 8 trays provide this information for a single direction. Fig. 3a shows the mass of Comp B deposited per m^2 as a function of distance for the HO detonations. The 60-mm rounds (average of 3 tests) deposited the least amount of Comp B and the quantity of explosives fell sharply with distance from the detonation. The mass-m^{-2} for the one 81-mm round generally decreased with distance but two increases, at 9 and 15 m, suggest the presence of particles. The one 120-mm round deposited the highest amount of HE. The mass per m^2 was fairly constant out to a distance of 13 m and then decreased by two orders of magnitude at 21 m. In general the amount of HE deposited decreases with distance from the detonation.

For the LO detonations the number of millimeter-sized particles per m^2 decreased with distance from the detonation (Fig. 3b). The smaller 60-mm (2 tests) and 81-mm

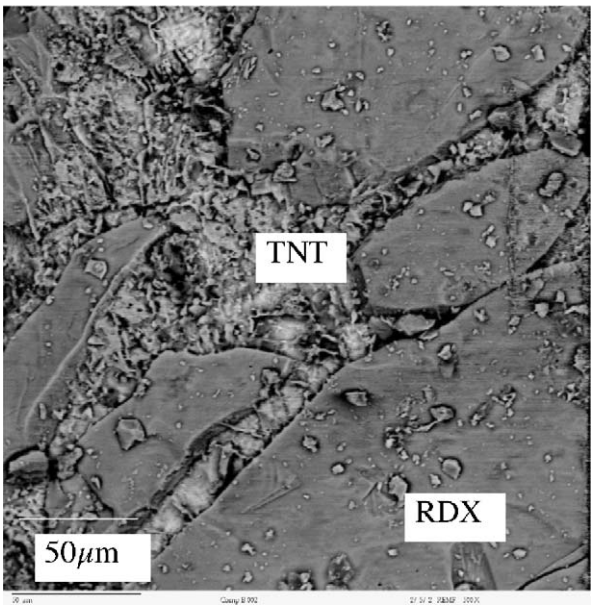

Fig. 2b. Scanning electron image of sectioned Comp B particle: light-colored areas are crystals of RDX; dark areas are TNT.

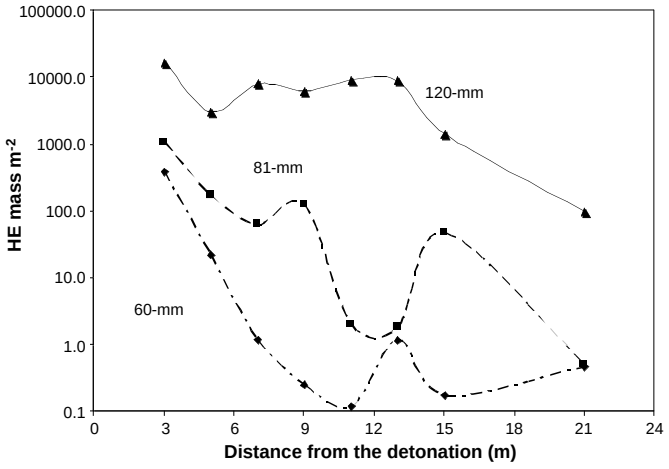

Fig. 3a. Comp B mass per m^2 as a function of distance for three 60-mm, one 81-mm and one 120-mm HO detonations.

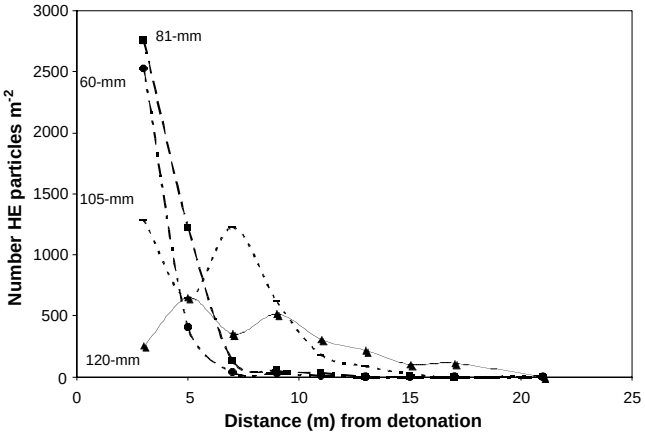

Fig. 3b. Number of Comp B particles per m^2 as a function of distance for 60-, 81-, 105- and 120-mm LO detonations.

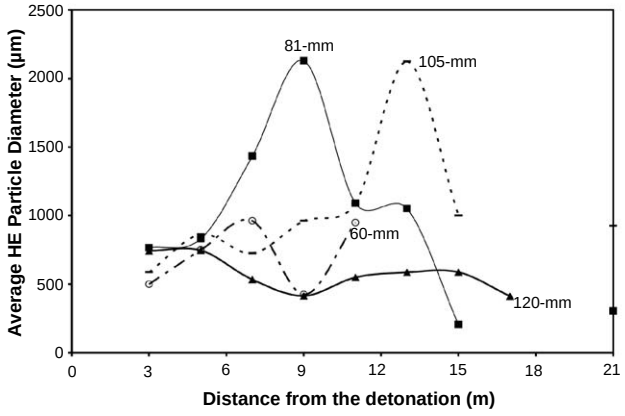

Fig. 3c. Average diameter of Comp B particles as a function of distance from the detonation. For figures b and c only those particles >250 μm are plotted.

rounds (3 tests) deposited many HE particles close to the detonation point and few particles beyond 7 m. The larger 105-mm (2 tests) and 120-mm rounds (four tests), on the other hand, deposited fewer particles close to the detonation and more particles farther from the detonation (Fig. 3b). The average size of the HE particles deposited by each of the LO rounds is shown in Fig. 3c. Close to the detonation point all rounds deposited Comp B particles 400–800 μm in size. With distance from the detonation the particle size initially increased and then decreased for the 60-, 81- and 105-mm rounds with the peak in particle size occurring at about 7, 9 and 13 m, respectively. The particles generated by the detonation of the 120-mm rounds did not significantly change size out to 17 m, the farthest distance sampled for these rounds. Generally the number of particles decreased, while the average diameter increased, up to a certain point, with distance from the detonation. This result is reasonable given that larger particles are less affected by air drag and can travel farther than small particles.

3.3. Estimates of total mass deposited

We estimated the total Comp B mass deposited by each detonation sampled by trays in the following way. We assumed the residue in the tray nearest the detonation was representative of the residue deposited in a circle having a radius equal to the distance from the detonation to the first tray. For the remainder of the trays we assumed that the mass on each tray was representative of a ring that encircled the detonation point at progressively larger radii. For example if the trays were placed at 3, 5, 7, 9, 11, 13, 15 and 19 m from the detonation point, the tray at 3 m would be used to calculate the residue in a circle of 3 m radius around the detonation. The tray at 5 m would be used to calculate the mass landing in a ring whose closest edge was 3 m and whose farthest edge was 5 m from the detonation. The tray at 19 m would be used to calculate the mass landing in a ring whose closest edge was 15 m and whose farthest edge was 19 m from the detonation. We multiplied the Comp B mass found on each tray by the area of the ring divided by the area of the tray. This fraction changes with distance from the detonation because the area of the ring increases. We realize that these mass estimates are highly uncertain, due to of small number of trays, the fact that the trays sample only a small percent of the 360° depositional area of the explosive residue, and that wind could preferentially transport the smaller explosive particles. Also the low-order detonations, in particular, are asymmetrical with respect to their HE deposition.

3.3.1. HO detonations

Table 2 shows the mass estimates for the HO rounds sampled. We collected and analyzed residues from three 60-mm rounds, and from one 81-mm and one 120-mm round. We have no data for the 105-mm HO detonations as the blast shredded the underlying tarp and small pieces of the tarp in the samples interfered with, and invalidated, our HPLC analysis.

We collected between 0.004 and 0.2 mg of TNT and RDX from the three HO, 60-mm detonations. We also detected HMX, at about one twentieth of the RDX mass, which we ascribe to a manufacturing impurity of RDX. Assuming our tray samples are representative of HE deposited on the tarp, we estimate that between 0.7 and 20 mg of Comp B, or between 4×10^{-4} and 1×10^{-2}% of the Comp B in the round, were deposited on the tarp (Table 2). Our values are higher than those estimated from live-fire residues collected on snow, 0.009–0.1 mg (Hewitt et al., 2003) and on the low end of estimates from other blow-in-place tests, 18–99 mg (Lewis et al., 2002) for the same munition.

Results for the 81-mm round are shown in Table 2. An estimated 0.4 mg of Comp B was deposited on the trays out to a distance of 16 m from the detonation. The estimate for the tarp is 41 mg or 5.6×10^{-3}% of the initial Comp B. This value is about four times higher than live-fire tests of 81-mm rounds that averaged 8.5 mg (Hewitt et al., 2003) and 9.5 mg (Walsh et al., 2005a) and is bracketed by results

Table 2
Mass of Comp B in 0.3 m^2 trays from HO detonations of 60-mm, 81-mm and 120-mm rounds

	Distance from detonation (m)	HE mass on tray (mg)	Area of ring (m^2)	Estimated Comp B on tarp (mg)
60-1	3	1.97E−01	28	19
2	5	2.21E−03	50	0.4
3	7	6.00E−05	75	0.02
4	9	8.00E−05	101	0.03
5	11	7.00E−05	126	0.03
6	13	7.50E−05	151	0.04
7	15	8.00E−05	177	0.05
8	21	3.10E−04	678	0.7
		1.99E−01		20
60-2	3	1.51E−01	28	14
2	5	1.73E−02	50	3
3	7	9.20E−04	75	0.2
4	9	3.50E−05	101	0.01
5	11	2.00E−05	126	0.01
6	13	4.30E−04	151	0.2
7	15	4.00E−05	177	0.02
8	19	1.25E−04	427	0.2
		1.68E−01		18
60-3	3	2.99E−03	28	0.3
2	5	1.60E−04	50	0.03
3	7	1.00E−04	75	0.03
4	9	1.10E−04	101	0.04
5	11	2.00E−05	126	0.01
6	13	5.45E−04	151	0.3
7	15	4.00E−05	177	0.02
8	19	0.00E+00	427	0.00
		4.00E−03		0.7
81-1	2	3.E−01	13	12
2	4	5.E−02	38	6
3	6	2.E−02	63	4
4	8	4.E−02	88	12
5	10	6.E−04	113	0.2
6	12	6.E−04	138	0.3
7	14	1.E−02	163	5
8	16	2.E−04	189	0.1
		4.E−01		41
120-1	3	5.02	28	468
2	5	0.94	50	157
3	7	2.44	75	610
4	9	1.89	101	635
5	11	2.76	126	1161
6	13	2.73	151	1374
7	15	0.44	177	260
8	17	0.03	201	20
		16.25		4685

from blow-in-place tests conducted on snow. The latter range from 12 mg to 6 g (Lewis et al., 2002; Hewitt et al., 2003; Walsh et al., 2005a).

The 120-mm round deposited about 16 mg of Comp B on our trays and we estimate that about 5 g were deposited on the tarp by this detonation (Table 2) or 0.15% of the explosive in the original round. This value is considerably higher than values obtained from the live-fire of 120-mm into a snow cover, which ranged from 0.5 to 20 mg (Hewitt et al., 2003; Walsh et al., 2005b). The fraction deposited was much higher than for the 60- and 81-mm rounds although the experimental set-up was the same. With only one test it is difficult to say if the high Comp B value reflects variability in residues remaining from HO explosions of 120-mm rounds or is a function of the thicker shell casing. We know of no other blow-in-place tests.

3.3.2. LO detonations

We collected and measured the residue deposited on trays for three 60-mm, two 105-mm, and the four 120-mm rounds detonated at low order (Table 3). We estimated the amount of Comp B deposited by two, 60-mm detonations at 11 g for LO-1 and 136 g for LO-2 (Table 3). These values represent 6% and 72% of the original HE fill in the round. Estimates for two low-order 105-mm detonations are 224 and 345 g (Table 3) or 10–15% of the Comp B originally in the round. We estimated that the four low-order detonations of 120-mm rounds deposited between 127 and 614 g of Comp B on the tarp (Table 3). These values represent 4–21% of the Comp B in the round.

For two 81-mm LO detonations we tried to collect all of the deposited residue. We collected and weighed all cm-sized pieces of explosive, swept the rest of the residue from the entire tarp and collected samples from the 8 trays. We estimated the mass deposited on the tarp two ways: first by using the tray samples, as was done previously, and second by sub-sampling sieved fractions of the material swept from the tarp. In both cases, the mass of the cm-size pieces picked up off the tarp was added to the mass of the mm-sized and smaller Comp B particles estimated from the trays or the tarp. In one case, LO 81-1, Comp B was found in a piece of the remaining shell. Its mass was estimated from the dimensions of the shell as we were not allowed to remove the HE from the shell.

For the first estimate, Comp B on the trays was separated from non-explosive particles and then weighed and photographed. If the trays are representative of the tarp we estimate that 70 g of the mm-sized fraction were deposited by LO-1. The weight of the >1 cm pieces removed from the tarp was 224 g and approximately 200 g of Comp B remained in the shell for a total mass of 494 g of Comp B deposited by LO-1. For LO-2 we estimated 146 g of mm-sized Comp B particles from the 8 trays. The weight of the >1 cm pieces removed from the tarp was 18 g and no Comp B remained in the shell for total mass of 164 g of Comp B deposited by LO-2 (Table 4). These values are 68% and 23% of the Comp B in the round.

We then estimated the mass deposited using the residue swept from the entire tarp. This material was sized into four size fractions, >4 mm, 2–4 mm, 0.25–2 mm and <0.25 mm. For these calculations we multiplied the mass of Comp B particles in the sub-sample by the total mass swept from the tarp in that size fraction divided by the mass of the sub-sample. Using the tarp sub-samples, we estimated the mass of Comp B on the tarp as 9 g for LO-1, and 33 g for LO-2 (Table 4). Adding in the cm-sized

Table 3
Mass of Comp B in 0.3 m^2 trays from LO detonations of 60-, 105- and 120-mm rounds

	Distance from detonation (m)	HE mass on tray (g)	Area of ring (m^2)	Estimated HE on tarp (g)
60-1-1	3	0.089	28	8.3
2	5	0.013	50	2.2
3	7	0.002	75	0.53
4	9	0.000	101	0.14
5	11		126	
6	13		151	
7	15		177	
8	21		678	
		0.104		11
60-2-1	3	0.148	28	13.8
2	5	0.165	50	27.5
3	7	0.051	75	12.6
4	9	0.003	101	1.08
5	11	0.194	126	81.3
6	13		151	
7	15		177	
8	19		427	
		0.561		136
105-1-1	3	0.06	28	6
2	5	0.06	50	10
3	7	0.13	75	33
4	9	0.16	101	53
5	11	0.15	126	62
6	13	0.13	151	66
7	15	0.09	177	52
8	19	0.04	427	63
		0.82		345
105-2-1	3	0.21	28	20
2	5	0.20	50	33
3	7	0.11	75	28
4	9	0.13	101	43
5	11	0.07	126	30
6	13	0.14	151	70
7	15	0	177	0
8	19	0	427	0
		0.86		224
120-1-1	3	0.569	28	53
2	5	0.768	50	128
3	7	0.158	75	40
4	9	0.387	101	130
5	11	0.312	126	131
6	13	0.120	151	61
7	15	0.122	177	72
		2.436		614
120-2-1	3	4.202	28	118
2	5	4.337	50	217
3	7	0.159	75	12
4	9	0.166	101	17
5	11	0.255	126	32
6	13	0.091	151	14
7	15	0.031	177	5
		9.241		414
120-3-1	3	0.420	28	12
2	5	0.375	50	19
3	7	0.226	75	17
4	9	0.255	101	26
5	11	0.099	126	12
6	13	0.106	151	16
7	15	0.092	177	16
8	17	0.047	201	9
		1.620		127
120-4-1	3	0.170	28	16
2	5	0.236	50	39
3	7	0.067	75	17
4	9		101	0
5	11	0.056	126	23
6	13	0.110	151	55
7	15		177	
8	17		201	
		0.639		135

pieces collected from the tarp and any left in the shell brings the totals to 433 g and 51 g respectively. These values are 47%, and 5% of the Comp B in the original round (Table 1).

Comparing the results of the two methods we find that the tarp sub-samples give substantially lower estimates than those obtained using the tray data. This is particularly evident for LO-2. Two likely explanations are that (1) the tarp sub-samples were not representative of the sample swept from the tarp, and (2) that, because of the asymmetrical distribution of residue, the tray samples captured above average HE mass. These estimates have large uncertainties because both methods estimate the total mass from the mass of small sub-samples.

These tests are difficult to conduct. Yet clearly more tests are needed to understand the variability possible with both HO and LO detonation of munitions, as these values significantly affect range load estimates. Also more comparison with live-fire results is needed to establish whether the type of initiation or the experiment sampling might account for the large differences in residues recovered.

4. Conclusions

We sampled residue from HO and LO blow-in-place detonations of Comp B-filled mortars and projectiles. The deposited Comp B varied from white, gray, or pink crystalline particles, to rounded yellow and black particles that had been heated, to yellow and black spheres that had been melted. Analyses of individual Comp B particles show that their TNT/RDX ratio varies considerably from the manufactured 39–60 ratio. We see no systematic trend in the RDX to TNT ratio with increased heating of the particles and think the varying ratios are likely due to the discrete nature of the RDX and TNT.

The HO detonation residues contained many small metal droplets and the 60-, 81- and 105-mm rounds deposited about 10^{-3}% of the Comp B originally in the round. The 120-mm round deposited more Comp B, about

Table 4
Mass of Comp B estimated for the same two LO detonations of 81-mm rounds using tray and tarp samples

Trays	Tray distance (m)	No. of HE particles	Ave. dia. (mm)	Area of ring (m^2)	Wt. of Comp B particles (g)	Estimated HE on tarp (g)	Wt. of HE pieces (g)	HE in shell (g)	Total wt. (g)
81-1-1	2	2202	0.48	13	0.13969	5.8			
2	4	614	0.45	38	0.0622	7.8			
3	6	56	0.96	63	0.108	22.5			
4	8	21	1.54	88	0.0584	17.0			
5	10	11	1.85	113	0.0295	11.0			
6	12	3	2.1	138	0.0124	5.7			
7	14	3	0.41	163	0.0001	0.05			
8	16	4	0.61	189	–	–			
						69.8	224	~200	~494
81-2-1	2	284	1.05	13	0.3466	14.4			
2	4	118	1.21	38	0.1185	14.8			
3	6	23	1.91	63	0.1551	32.3			
4	8	11	2.72	88	0.1411	41.1			
5–8	10–16	8	0.33	603	0.0216	43.1	0.2296		
						145.7	18	None	164

Tarp	Swept from tarp (g)	Sub-sample wt. (g)	No. of Comp B particles	Wt. of HE in sub-sample (g)	Estimated wt. on tarp (g)	Wt. of HE pieces (g)	HE in shell (g)	Total wt. (g)
81-1								
>4 mm	16	1.13	0	0	0.0			
2–4 mm	24	0.73	1	0.073	2.4			
0.25–2 mm	100	2.79	1298	0.1886	6.8			
<0.25 mm	18	1.6	HPLC	1.20E−02	1.4E−01			
					9.3	224	~200	~433
81-2								
>4 mm	27	0.26	0	0	0.0			
2–4 mm	8	0.2	0	0	0.0			
0.25–2 mm	141	2.37	n.c.	0.53	3.2E+01			
<0.25 mm	82	2.5	HPLC	5.00E−02	1.6E+00			
					33.2	18	None	51

Determined by HPLC analysis; n.c., not counted.

0.15% of its original HE mass. We found that the amount of HE decreased as a function of distance from the detonation. The 60-mm rounds deposited less HE than the 81-mm round, which deposited less HE than the 120-mm round.

The LO detonations distributed 5–50% of the Comp B in their shell onto the tarp. The mass estimates are subject to large uncertainties because of the small number of trays used to collect the residue and because LO detonations, much more so than HO detonations, are asymmetrical with respect to their HE deposition. Clearly if large chunks of explosives are dispersed, such as occurred for the 81-mm LO-1, these need to be collected and weighed as they may represent most of the mass.

For millimeter-sized Comp B particles deposited by LO detonations, our data show a decrease in their number with distance from the detonation point. The 60-mm and 81-mm rounds deposit the highest number of Comp B particles within 7 m of the detonation. The 105- and 120-mm rounds, on the other hand, do not show an abrupt decrease in the number of HE particles deposited per m^2 as a function of distance. Although the number of Comp B particles per m^2 does decrease with distance from the detonation, it does so gradually suggesting that the 105- and 120-mm rounds have 'footprints' about 20 m in radius. These BIP detonations also suggest a general increase in the amount of residue deposited as the amount of explosive fill in the round increases.

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